

Characterization of Encapsulated Corrosion Inhibitors for Environmentally Friendly Smart Coatings

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Corrosion

- Worldwide corrosion cost: \$2.2 trillion (2010)
- US cost: ~\$1 trillion (2013)
- Replace current corrosion inhibitors with environmentally friendly alternatives
 - Coating compatibility issues
 - Solubility issues





Delivery System



Coating compatibility Inhibitor solubility

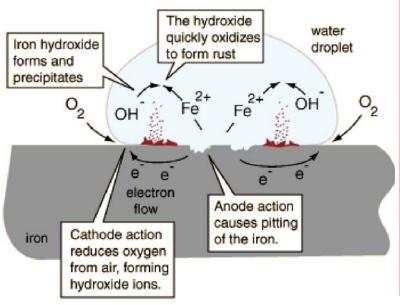
Corrosion Protection

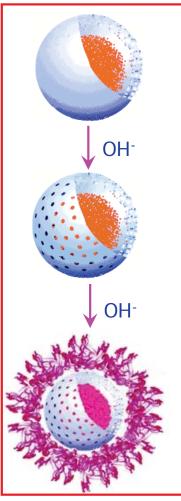


Coating

KSC Approach

- "Smart coating" for corrosion sensing and control
 - Autonomous
 - pH controlled
 - Universal



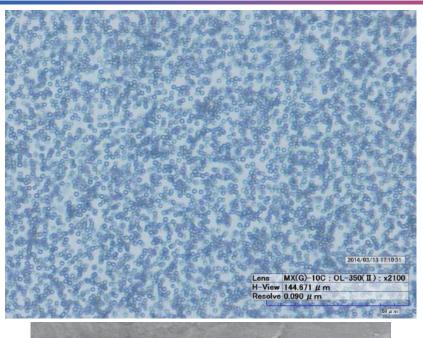


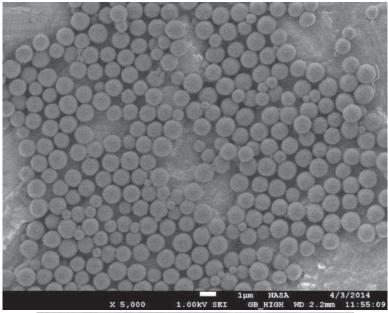
Microcapsule containing pH indicator (inhibitor, self healing agents)

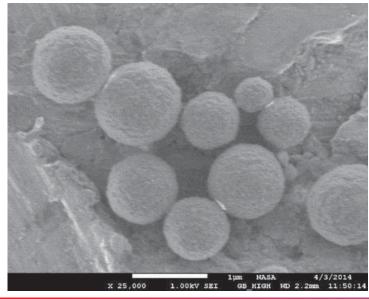
The shell of the microcapsule breaks down under basic pH (corrosion) conditions

pH indicator changes color and is released from the microcapsule when corrosion starts

Emulsion Polymerization

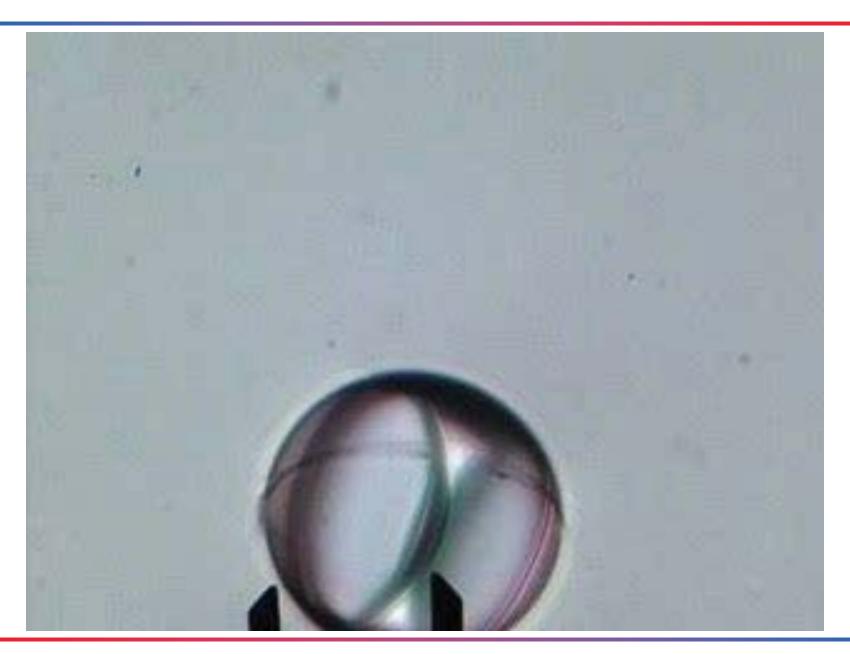








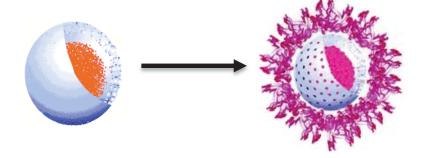
Release Video



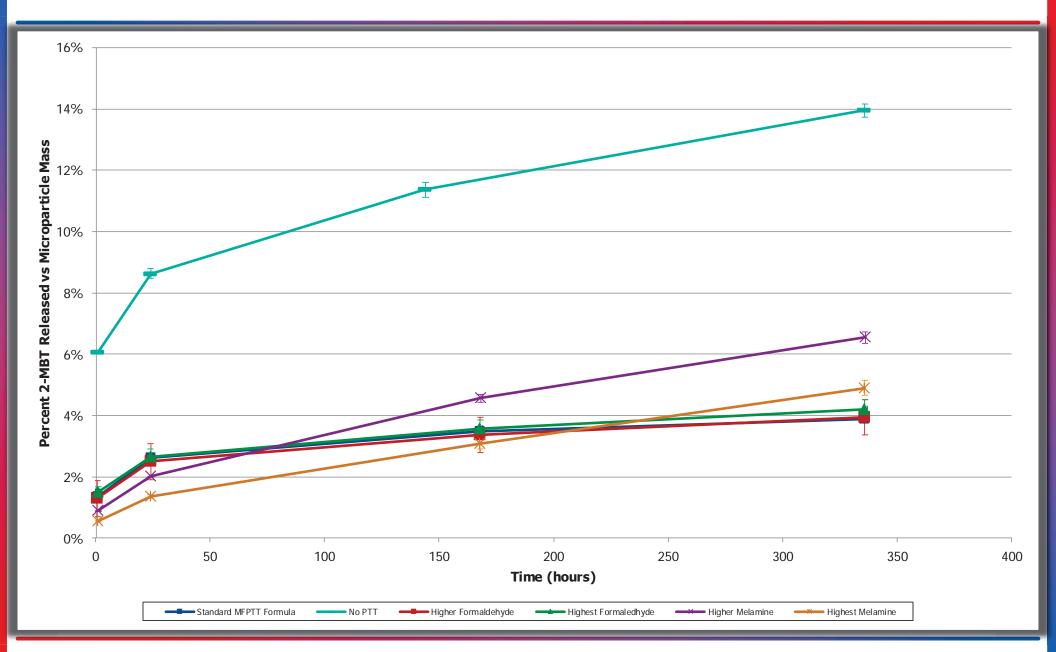
RELEASE STUDIES

Inhibitor Release

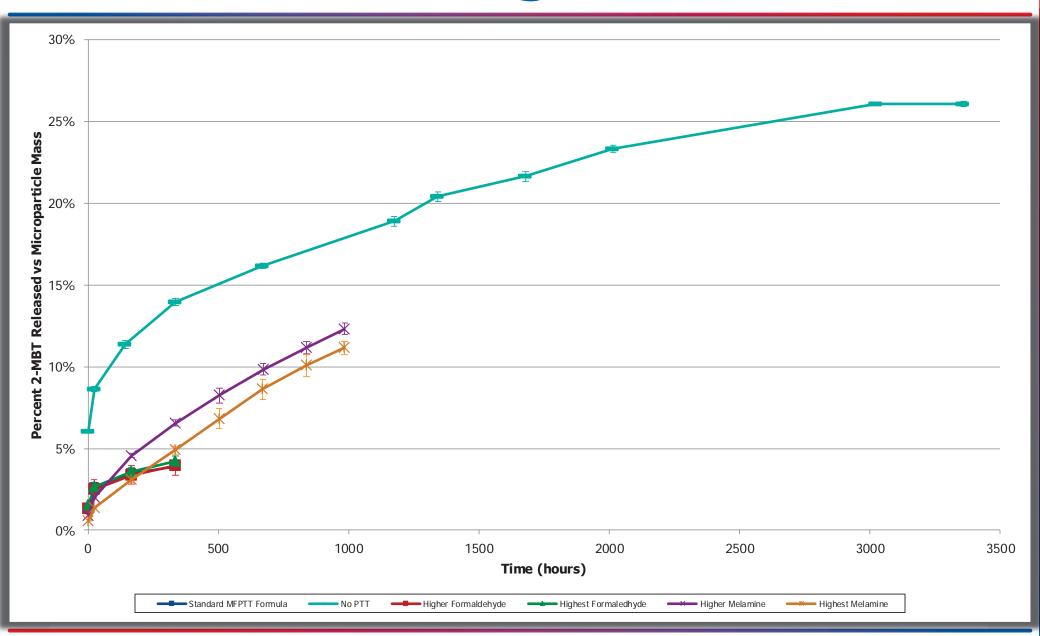
- Determine release of inhibitor with time
 - 2-Mercaptobenzothiazole (2-MBT)
 - Nitrite
 - Molybdate
- Method
 - Immersion of particles into 0.01 M base
 - Sampling at regular intervals



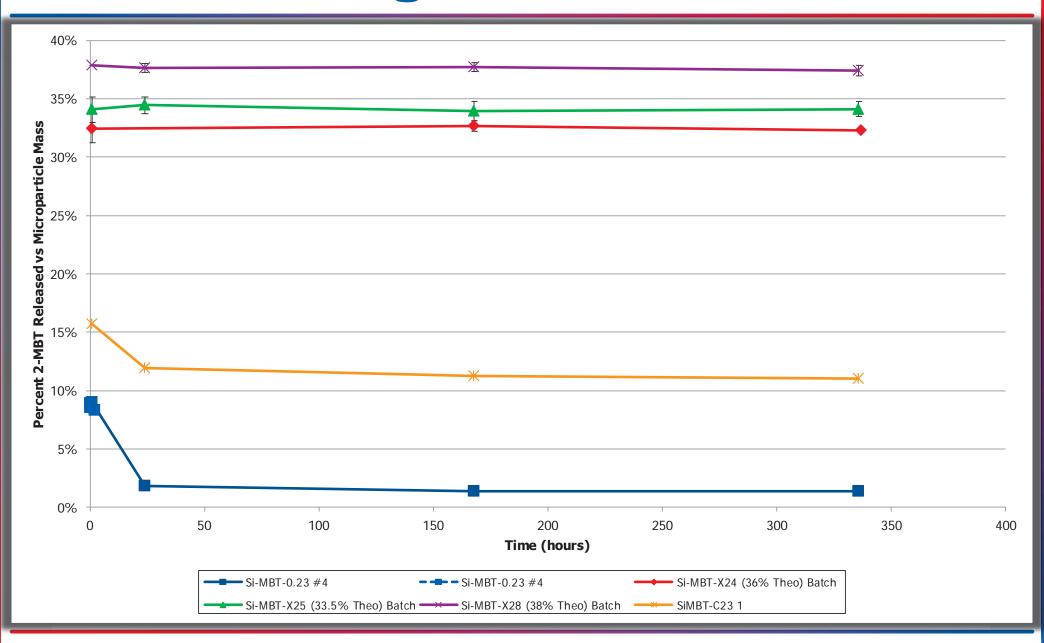
MF: 2-MBT Short-term Release



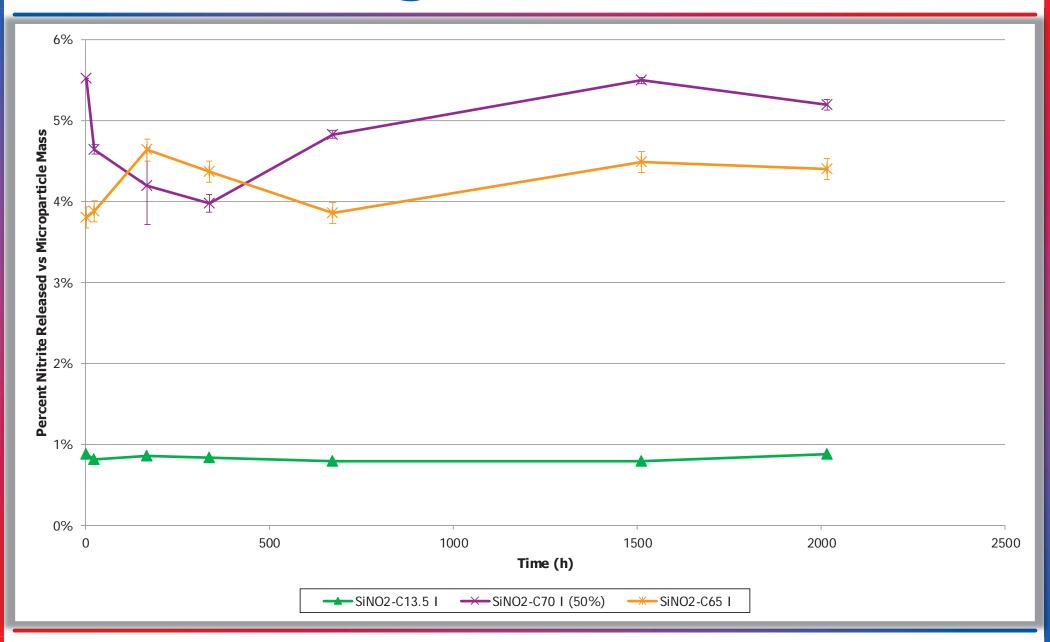
MF: 2-MBT Long-term Release



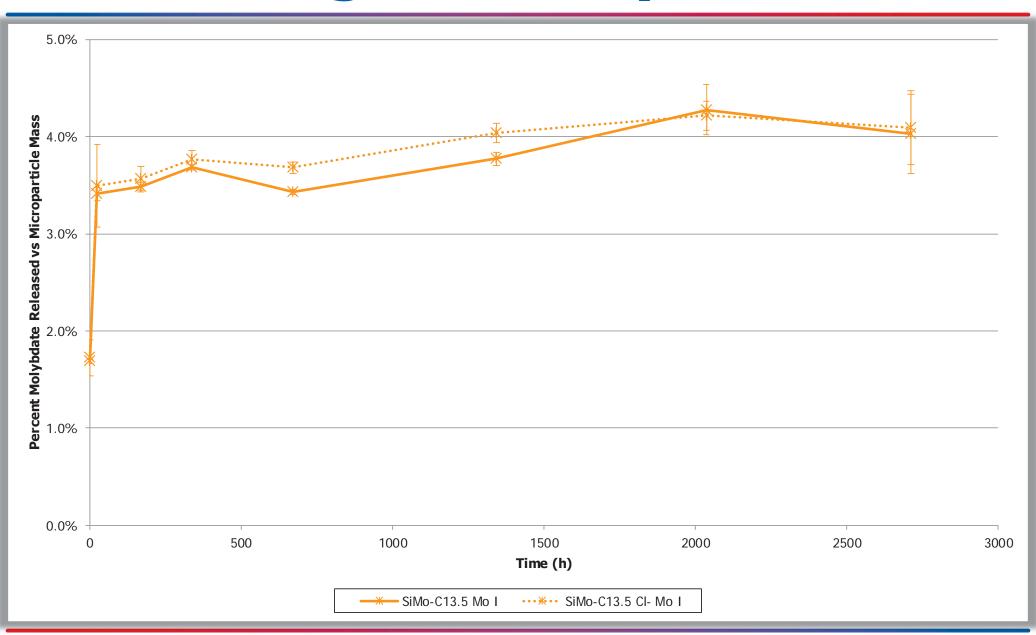
Inorganic: 2-MBT



Inorganic: Nitrite



Inorganic: Molybdate



Release Studies

- Successful encapsulation and release of inhibitor
- Organic particles
 - Inhibitors can react with particle material
 - Slower, longer-term release
- Inorganic particles
 - Can incorporate a variety of inhibitors, including highly water soluble ionic compounds
 - Quicker, higher amount release

ELECTROCHEMICAL CORROSION TESTING

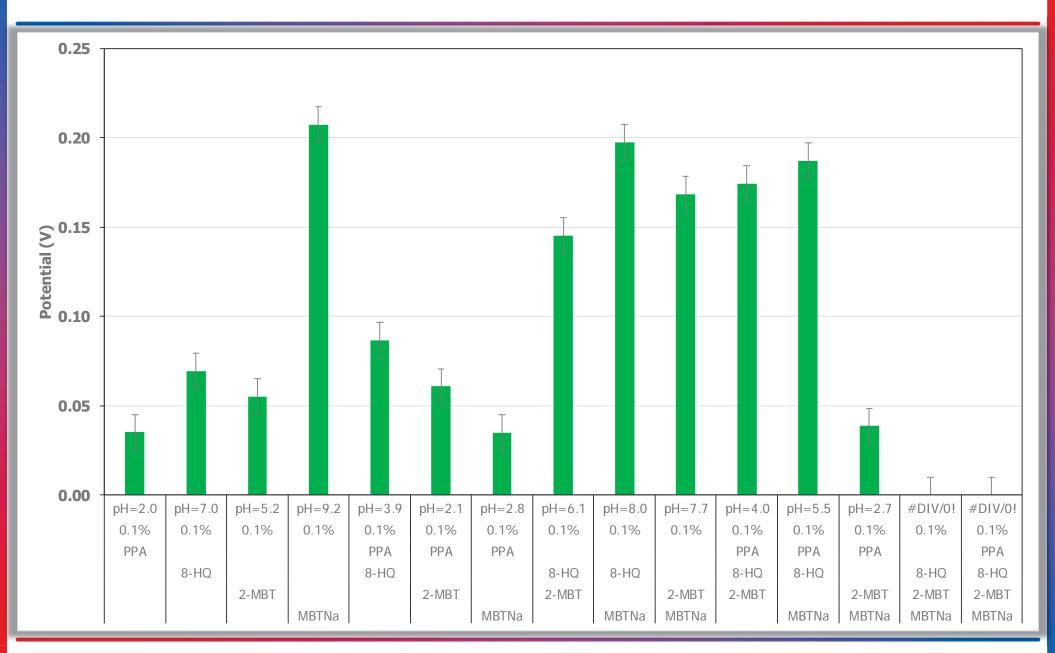
Accelerated Corrosion Testing

- Carbon steel in 3.5% NaCl solution
- Electrochemical measurements
- Salt immersion
 - Phenylphosphonic acid (PPA)
 - 8-Hydroxyquinoline (8-HQ)
 - 2-MBT & Sodium 2-Mercaptobenzothiazole (2-

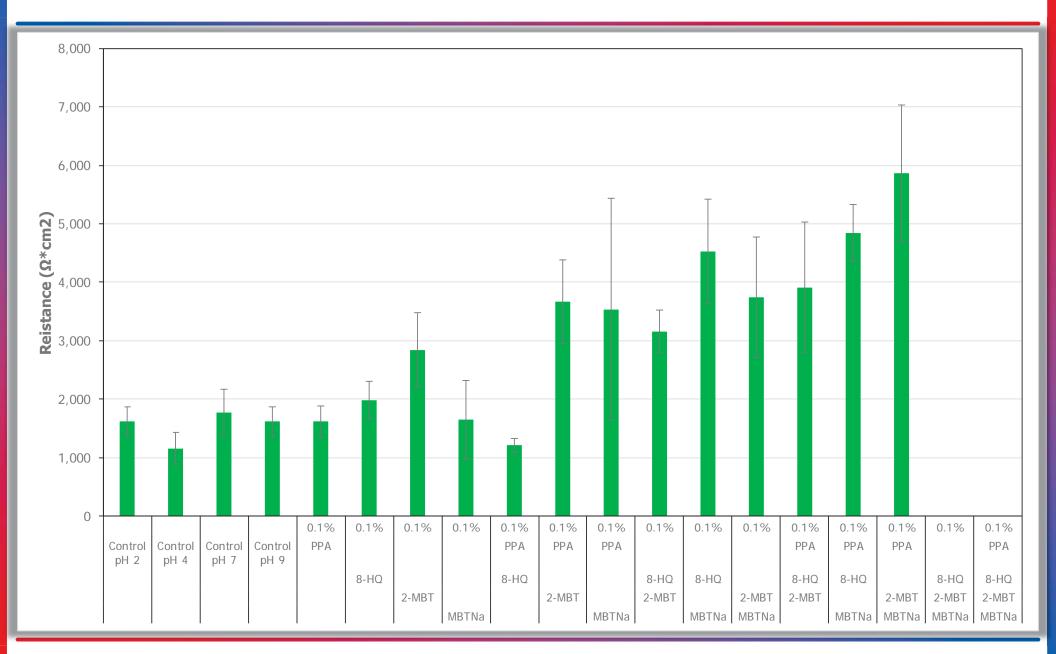
MBTNa)



Corrosion Potential Increase



Polarization Resistance



SALT IMMERSION TESTING

Pure Inhibitor: PPA

Time	Control	0.1% PPA	0.1% PPA and 0.1% 8- HQ	0.1% PPA and 0.002% 2-MBT	0.1% PPA and 0.1% NaMBT	0.1% PPA, 0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA, 0.1% 8-HQ and 0.1% NaMBT
Initial							
5 hour	Control	D.1% PPA	Q 1% PPAQ 1% HQ	0.1% PPA/0.002% MRT	O IN PPACIE NAMOT	0.1% HQI0.1% PPA-0.002% MBT	0.1% HQ/0.1% PPA0.1% NaMBT
6 day	Control	0.1% PPA	0 1% PPA 0 1% HO	0.1% PPA0.00% M6T	0.1% PPAID.1% NAMBT	DIS HOO IS PPAID DOPS MY	Q.1% HQQ.1% PPAQ.1% Navigy
After Wash				,			

Pure Inhibitor: 8-HQ

Time	Control	0.1% 8-HQ	0.1% 8-HQ and 0.002% 2-MBT	0.1% 8-HQ and 0.1% NaMBT	0.1% PPA and 0.1% 8- HQ	0.1% PPA, 0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA, 0.1% 8-HQ and 0.002% NaMBT
Initial							
5 hour	Corespi	2 (% HO)	0.1% HQ0.000% MIT	a the HOO THE NORMET	Q.1% PPAQ.1% HQ	0.1% HOO 1% PPA0.00% MBT	0.1% HQI0.1% PPA0.1% NAMST
6 day	Cortex	0.1%-HO	0.1% HO/0.00% MBT	0.1% HO/O.1% NaMBT	D 1% FFPAG.1% HZ	DISHOOTS PRACOOPS MIT	0 Ph H20.1% PPAO.1% No.MJ;
After Wash							

Pure Inhibitor: 2-MBT

Time	Control	0.002% 2-MBT	0.1% PPA and 0.002% 2-MBT	0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA,0.1% 8-HQ and 0.002% 2-MBT
Initial					
4/5 hour					
1 day					
Steel Piece					

Pure Inhibitor: 2-MBTNa

Time	Control	0.1% NaMBT	0.1% PPA and 0.1% NaMBT	0.1% 8-HQ and 0.1% NaMBT	0.1% PPA, 0.1% 8-HQ and 0.1% NaMBT
Initial					
1 hour					
1 day					
Steel Piece					

Particles: PPA

Time	Control	0.3% PPA Particles	0.3% PPA Particles 0.25% 8-HQ Particles	0.3% PPA Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial	Control	0.3% PPA Part	0.3% PPA Part / 0.25% 8-HQ Part	0.3% PP/ Part/0.004% 2-MBT Port	0.25% 8-HQ Part0.3% PPA Part0.004% 2-M0T Part
1 day	Control	0.3% PPA Part	0.3% PPA Part / 0.25% 8-HQ Part	03% PPA Hart/0.004% 2-NBT Par	0.25% 8 O PartiO.5% PPA PartiD.004% MBIT Part
6 day	Control	13% PPA Pari	0.3% PPA Part / 0.25% 8-HQ Part	03% PPA Part/0.004% 2-MBT Part	0.85° 8-HO Part/0.3% PDA DA 0.005% 2-M6°
Before Wash					

Particles: 8-HQ

Time	Control	0.25% 8-HQ Particles	0.3% PPA Particles 0.25% 8-HQ Particles	0.25% 8-HQ Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial	Control	0.25% 8-HQ Part	0.3% PPA Part / 0.25% 8-HQ Part	0.25% 8-HQ Part/0.004% 2-MBT Pa	0.25% 8-HO Parti 3% PPA Parti 0.00% 3-M07 Part
1 day	Control	0.25% 8-HQ Part	0.3% PPA Part / 0.25% 8-HQ Part	0.25% 8-h Part/0.004% 2-MBT	0 Part 0.3% PPA Part 0.00%. MET Part
6 day	Control	0.25% 8-HQ Part	0.3% PPA Part / 0.25% 8-HQ Part	0.25% 8-HQ Part/0.004% 2-MF	0.35° 3-HQ Part0.3% PD1 P-4 0.004% 2-M8
Before Wash					

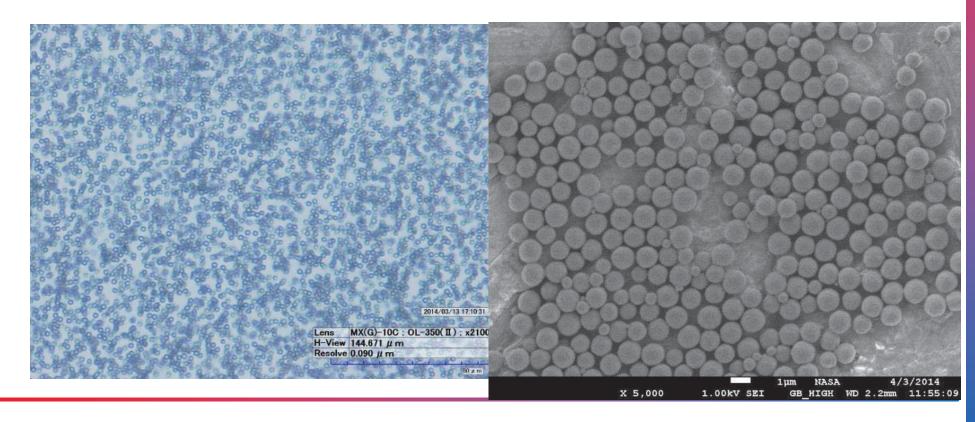
Particles: 2-MBT

Time	Control	0.009% Inorganic 2-MBT Particles	0.3% PPA Particles 0.004% 2-MBT Particles	0.25% 8-HQ Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial	Control	0.009% Inorg 2-MBT Part	0.3% PP/ Part/0.004% 2-MBT Port	0.25% 8-HQ Part 0.004% 2-MBT Par	0.25% 8-HQ Part0.3% PPA Part0.00% 2-46)T Part
1 day	Control	0.0 9% Inorg 2-N YT Part	0.3% PPA I art/0.004% 2-hiBT Part	0.25% 8-h Part/0.004% 2-MBT	0.25% © O PartiO.5% PPA PartiO.004% MBT Par
6 day	Control	0.009% Inoro 2-MBT Part	03% PPA Part/0.004% 2-MBT Part	0.25% 8-HQ Part/0.004% 2-MF	0.35 - 8-HQ PartQ 3% ppa pag agres 2-Mg
Before Wash					

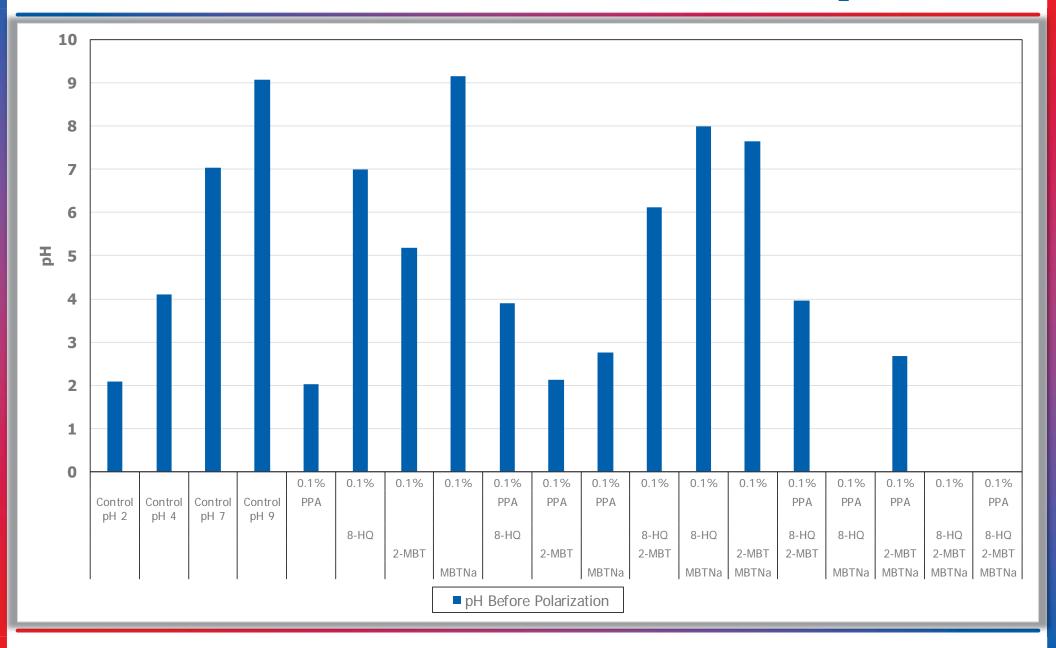
Conclusion

- Successful encapsulation of various inhibitors into organic & inorganic microparticles
- Release of inhibitor monitored over long periods of time → short- and longterm controlled release
- Corrosion protection of pure materials confirmed through electrochemical testing
- Particles effective at preventing corrosion in salt immersion testing
- Inhibitors combinations showing high corrosion inhibition efficiency

Synthesis: Organic Particles



Pure Inhibitor Solution pH



pH Change during Polarization

